Comparison of Stream Channel and Aquatic Habitat Conditions in Reference and Managed Watersheds

Flathead National Forest
2010

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Introduction

This report describes the current conditions of stream channels and associated aquatic habitats in reference and managed watersheds on the Flathead National Forest. There are two main purposes of this analysis: 1) to determine which stream habitat attributes may be most affected by contemporary management activities, and 2) to provide hydrologists and fisheries biologists a basis for assessment of streams to support project-level NEPA analysis.

Land management activities can have a wide variety of direct, indirect, and cumulative effects on streams over a wide range of spatial and temporal scales. Impacts may be measured by numerous attributes such as stream bank stability, particle size distribution, woody material, pool frequency and quality, water temperature and chemistry, and channel dimensions.

On the Flathead National Forest, timber harvest, fuel reduction, and recreation are the primary land management activities and they are supported by an extensive network of roads. Timber harvest has declined rapidly since about 1995. At this time, the forest began an aggressive road decommissioning program as directed by Forest Plan Amendment 19. Since that time, approximately 680 miles of road have been decommissioned. Streams may be affected directly by timber harvest and roads, especially when these activities are in close proximity. Indirect effects may occur due to changes in streamflow and/or sediment delivery processes.

A common challenge facing hydrologists and fisheries biologists is to determine the overall condition of streams and how these conditions might be different in the absence of land management activities in their associated catchments. This can be difficult because of so much variability associated with climate, geology, landform and soils, elevation, aspect, channel morphology, and forest disturbance regimes. The effects of land management activities on streams must be considered in the context of this spatial and temporal variability.

One way to gage the effects of land management on streams is to compare them with streams that are not affected by management (Kershner et al. 2004, Woodsmith and Buffington 1996). On a project-level basis, this approach can be used to compare stream habitat attributes of one stream with the range of values found in several reference streams located in similar geo-climatic settings. The reliance on reference conditions to evaluate stream condition is challenging because landscape characteristics of managed watersheds may be different than those of reference watersheds (Kershner et al. 2004). Therefore, comparison of distributions of stream habitat conditions in managed reaches with those of reference reaches may be adjusted by important independent variables such as geology, precipitation, and channel morphology.

Methods

This analysis uses data collected through the PACFISH/INFISH Biological Opinion (PIBO) monitoring program. This program was initiated by the Forest Service in 2001 and includes several hundred sites across the Columbia River Basin, which includes the Flathead National Forest (http://www.fs.fed.us/biology/fishecology/emp/). The Flathead National Forest has a total of 70 sites in reference and managed watersheds. Table 1 summarizes the key physical habitat data collected at PIBO monitoring sites.

Table 1. Key physical data collected at PIBO monitoring sites.

Category	Short Name	Long Name
Management	FEDPct	Percent FS / BLM
Management	Mgmt	Management category
Environment	Area	Catchment area upstream from the site
Environment	Elev	Elevation at the bottom of stream reach
Environment	Precip	Annual precipitation
Channel dimensions	Bf	Average bankfull width from transects
Channel dimensions	RchLen	Length of sampling reach
Channel dimensions	Grad	Gradient of stream reach
Channel dimensions	Sin	Sinuosity of stream reach
Channel dimensions	Pooldp	Residual pool depth
Channel dimensions	PoolFrq	Number of pools per kilometer
Channel dimensions	PoolPct	Percent pools
Channel dimensions	WDTrans	Bankfull width-to-depth ratio at transects
Channel dimensions	WDwetTrans	Wetted width-to-depth ratio at transects
Channel dimensions	WDRif	Bankfull width-to-depth ratio at riffles
Channel dimensions	WDwetRif	Wetted width-to-depth ratio at riffles
Substrate	D16	Diameter of the 16th percentile streambed particle
Substrate	D50	Diameter of the 50th percentile streambed particle
Substrate	D84	Diameter of the 84th percentile streambed particle
Substrate	PlFn2	Percent pool tail fines < 2mm
Substrate	PlFn6	Percent pool tail fines < 6mm
Streambanks	Stab	Percent stable banks
Streambanks	BnkAngl	Bank angle
Streambanks	UnCutPct	Percent of bank angles < 90°
Wood	LWfreq	Large wood frequency
Wood	LWvol	Large wood volume

The PIBO data set is the most robust data available on the forest. Data is collected at the majority of sites on a 5 year rotating panel. Therefore, most sites on the forest have at least two sets of data. The data is collected using strict QA/QC standards to maximize consistency and minimize variability associated with field crews. Field crews are required to attend two weeks of rigorous training before they are allowed to collect data.

The majority of reference sites are located in the Bob Marshall Wilderness in the South Fork Flathead and Middle Fork Flathead sub-basin, while managed sites are well distributed in the North Fork, Swan, and Stillwater sub-basins (Figure 1). Generally, reference streams are located in watersheds with minimal anthropogenic disturbances (i.e. Wilderness or roadless areas), and managed streams are within watersheds that have experienced management activities during the last several decades. In the case of the Flathead National Forest, managed watersheds are primarily affected by timber harvest and roads. There are a total of 42 managed sites and 28 reference sites (Figure 1).

Geologic parent material is made up of Pre-Cambrian rocks belonging to the Belt Super-group. Common lithology includes argillite, siltite, quartzite, and limestone. The entire forest was affected by continental glaciation that ended approximately 12,000 years ago. The Flathead Lobe of the Cordilleran ice sheet was approximately 4,000 feet deep and extended as far south as Ronan. This glacial activity left behind a complex array of landforms including outwash fans and terraces, glacial moraines, lacustrine deposits, floodplains, terraces, and extensive till deposits. Soils are strongly influenced by landforms, climate, and volcanic ash. Silt loam is the dominant texture and most soils contain small rock fragments. Average annual precipitation is strongly influenced by elevation and ranges between 15 and 100 inches. The fault block mountains on the east side of the forest receive the most precipitation, while the salish mountains on the west side of the forest receive a maximum of 30 inches.

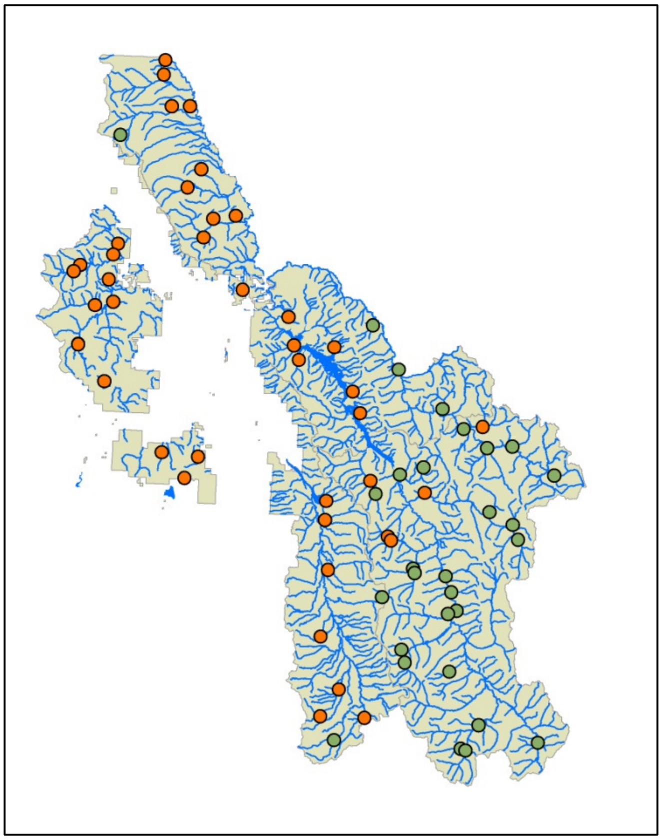

Figure 1. PIBO monitoring sites. Green dots represent reference sites and orange dots represent managed sites.

Specific stream attributes addressed in this report include residual pool depth, bank stability, bank angle, undercut banks, and median particle size. These are the same attributes found to be most affected by management activities in the Columbia Basin (Kershner et al. 2004). The Kershner et al. (2004) study used ANCOVA techniques to analyze the difference between reference and managed sites using mean bankfull width, gradient, and average annual precipitation as covariates. To assess differences between reference and managed stream conditions on the Flathead National Forest only, an identical analysis was conducted in 2008 using the same covariates identified by Kershner et al. (2004). These covariates include mean bankfull width, gradient, and precipitation. The percentage of reach in forested condition was identified as a fourth covariate. In addition, another statistical test was completed using multiple regressions for each response variable with the covariates as independent variables using the reference data only. This approach basically uses the reference data to predict variables in managed sites. The residual values are then tested against the reference values to determine significance. These statistical analyses were provided by Robert Al-Chokhachy (PIBO Monitoring Group, Logan, Utah).

Results

The results of the ANCOVA are shown in Table 2. Percent undercut banks is the only variable that shows statistically significant differences between reference and managed sites (P<0.10). However, these results may be misleading because of the high variance and small sample size of the reference data.

Table 2. ANCOVA-adjusted means and standard error values of reference and managed sites on the Flathead National Forest.

	ANCOVA RESULTS				
Variable	**Managed Mean (n=42)**	**Managed SE**	**Reference Mean (n=28)**	**Reference SE**	***P*-value**
Residual Pool Depth (m)	0.36	0.029	0.34	0.04	0.59
Percent Pools	43.7	2.8	44	3.6	0.95
Median Particle Size (m)	0.047	0.004	0.052	0.01	0.42
Percent Pool Tail Fines	13.1	1.2	14.3	1.2	0.75
Percent Undercut Banks	32.3	2.8	22.0	3.6	0.03

Table 3. Regression analysis of reference and managed sites on the Flathead National Forest.

	REGRESSION RESULTS				
Variable	**Mean Residuals Managed (n=42)**	**Managed SE**	**Mean Residuals Reference (n=28)**	**Reference SE**	***P*-value**
Residual Pool Depth (m)	-0.117	0.04	0	0.033	0.0004
Percent Pools	-3	2.7	0	3.1	0.27
Median Particle Size (m)	-0.014	0.005	0	0.004	0.003
Percent Pool Tail Fines	1.4	2.7	1	2.4	0.03
Percent Undercut Banks	5.77	3.64	0	2.88	0.12

The regression approach yielded significance differences (*P*<0.10) for residual pool depth, median particle size, and percent pool tail fines, but not for undercut banks. Interestingly, the results show unexpected differences in the mean values for percent undercut banks, with managed sites having more undercut banks than reference sites. Practitioners in forest hydrology and fisheries often assume that roads and timber harvest can potentially change streamflow patterns and result in bank erosion and channel widening. The results of this analysis may be in conflict with these assumptions. A plot of bankfull width vs. drainage area indicates that managed sites are generally narrower than reference sites (Figure 3). The curves in Figure 3 may also be influenced by average annual precipitation. Many of the reference sites are located in areas of higher precipitation, which may explain (in part) the differences between the two curves.

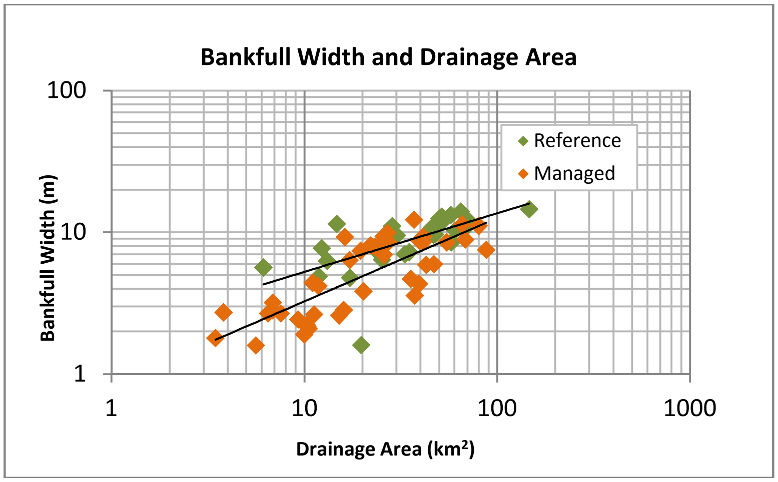

Figure 3. Drainage area and bankfull width of reference and managed streams.

The ANCOVA results suggest that management activities are not measurably affecting sediment-related attributes. By contrast, the regression approach yielded small, but significant differences in residual pool depth, median particle size, and percent pool tail fines (Table 2). As stated earlier, bankfull width, gradient, and precipitation are the covariates used in both statistical approaches. Bankfull width is a good surrogate for relative stream size and reach gradient is a relatively good predictor of particle size distribution. However, average boundary shear stress may be a more useful covariate that is worth exploring. For example, Woodsmith and Buffington (1996) compared 23 streams in disturbed and undisturbed watersheds in southeast Alaska. They found that the ratio of critical sheer stress (based on median grain diameter) to bankfull shear stress (τ_c / τ_{bf}) was a useful indicator in discriminating between reference and managed sites. This indicator (covariate) was used in conjunction with others such as pool frequency, residual pool depth, and mean depth at bankfull stage. τ_c / τ_{bf} is a ratio of the critical shear stress needed to mobilize a given particle size to the average shear stress of the stream at bankfull stage. It is a theoretical measure of existing particle size relative to the minimum flow required to mobilize it. Low ratios may indicate greater supplies of fine sediment and high ratios may indicate scoured channels with abundant stream power. Shear stress (τ_{bf}) is a measure of average force per unit area acting on the streambed (Leopold 1994). It may be computed using the formula below.

$$\tau_{bf} = \gamma_w d_{bf} S$$

Where,

γ_w = the specific weight of water
d_{bf} = reach averaged depth at bankfull stage
S = the slope of the reach

Typically, the hydraulic radius is used instead of mean depth, particularly when using the shear stress metric to predict sediment transport. However, mean depth is a reasonable surrogate, particularly for wider channels. Critical shear stress (τ_c) relates to a given particle and describes the relative force needed to mobilize it. For the median particle size, critical shear stress is estimated using the formula below.

$$\tau_c = \theta(\gamma_s - \gamma_w)D_{50}$$

Where,

θ is the critical dimensionless shear stress. (constant estimated at 0.05[1])

γ_s equals the specific weight of sediment.

γ_w = the specific weight of water

Figure 4 contains cumulative frequency distributions of τ_c / τ_{bf} of reference and managed sites. Average boundary shear stress may also be an important covariate or predictor of other sediment-related attributes such as the D_{16}, the D_{50}, and percent pool tail fines (Figures 5-7). It is also apparent that shear stress is a better predictor of particle size, at least for managed streams. The correlation coefficient for the managed D_{50} (Figure 6) is 0.363 compared to that of 0.080 when stream gradient is alone.

Bryce et al. (2010) suggests a sediment tolerance value for salmonids of no more than 13% of particles less than 2 mm in size. This suggested value is shown in Figures 5 and 7 for additional context. Box plots shown in Figure 8 show the D_{16} for reference and managed sites. This value is three percentage points above the 13% value suggested by Bryce et al. (2010), but still provides some insight into sediment characteristics of reference and managed streams in relation to salmonid habitat requirements.

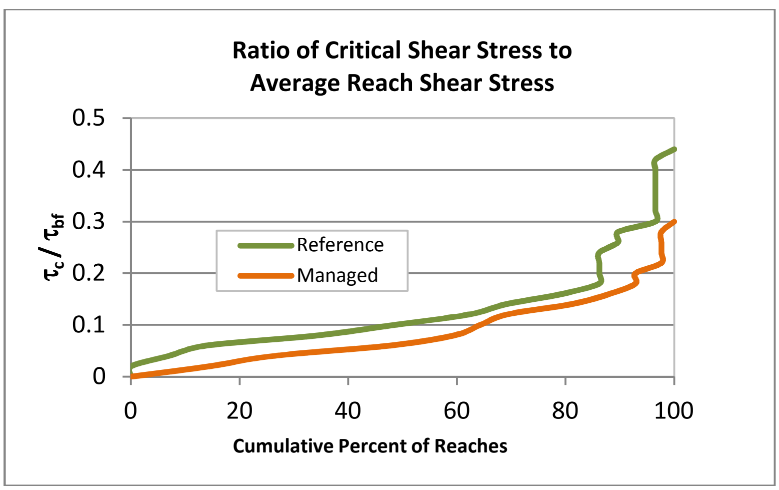

Figure 4. Cumulative frequency distributions of τ_c / τ_{bf} in reference and managed stream reaches.

[1] Andrews 1983

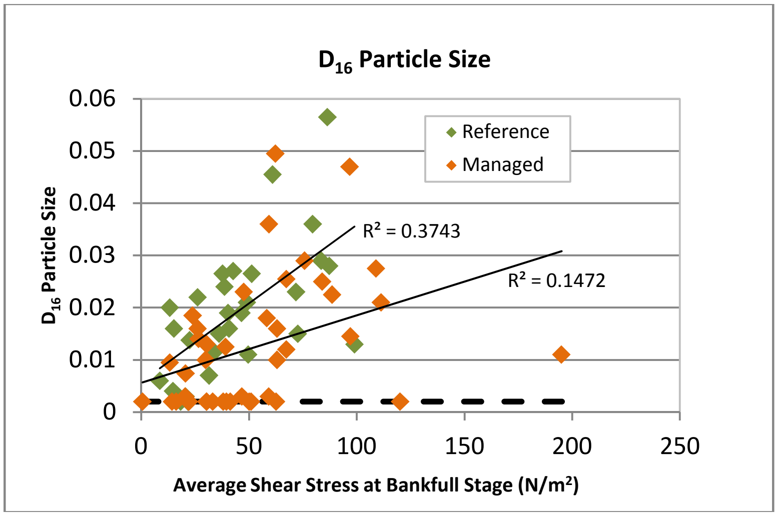

Figure 5. D_{16} as a function of reach-averaged shear stress at bankfull stage. The dotted line represents the 2 mm size class.

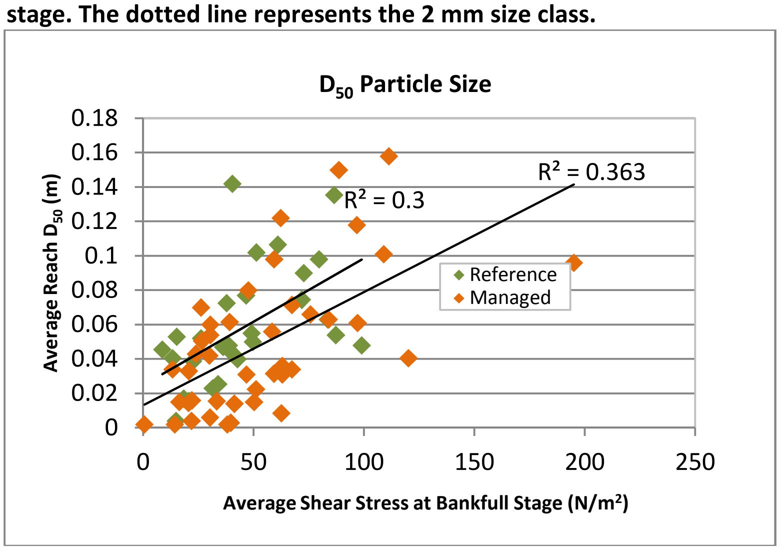

Figure 6. D_{50} as a function of reach-averaged shear stress at bankfull stage.

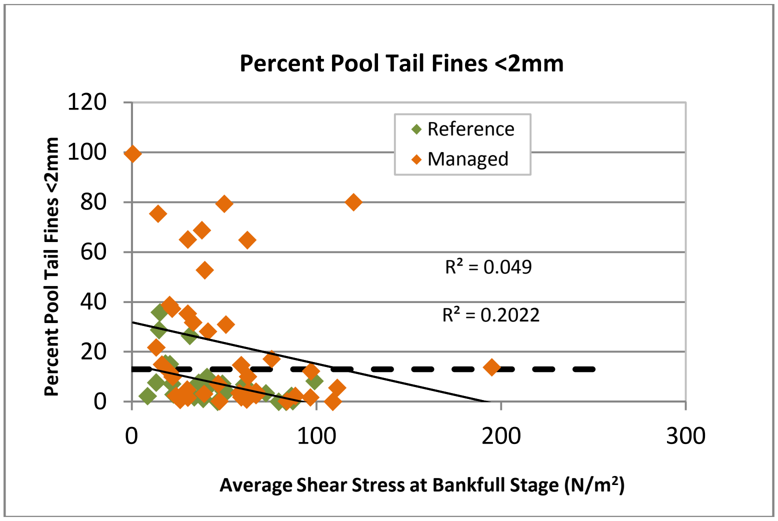

Figure 7. Percent pool tail fines as a function of reach-averaged shear stress at bankfull stage. The dotted line represents the 13% sediment tolerance value for sands and fines identified by Bryce et al. 2010.

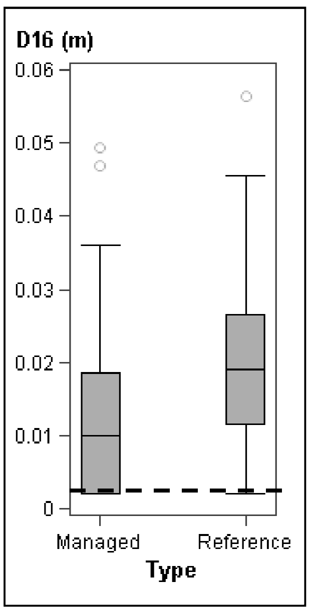

Figure 8. Box plots of the D16 in reference and managed sits. The dashed line is the 2 mm

Discussion

The results indicate that streams in managed watersheds have slightly higher levels of fine sediment. This material most likely originates from forest roads. However, some managed sites appear to have fine sediment levels that are still well below the recommended sediment tolerance value for salmonids (Figure 7).

The results associated with bankfull channel width are perplexing. A long held assumption by practitioners in forest hydrology and fisheries management is that roads and associated forest management activities can potentially change streamflow patterns (i.e. timing, magnitude, duration, etc.), and that these changes can result in streambank erosion and channel widening. Intuitively, these assumptions seem appropriate. However, the results of this analysis indicate that these impacts may not be occurring, at least in low gradient response reaches with drainage areas greater than 3 km^2 (Figures 2 and 3). A more in-depth analysis of bankfull width in reference and managed streams is needed. Effects of forest management on water yield and peak flows have been studied extensively, but surprisingly, there is very little information on how changes in streamflow (due to forest management) change stream channels. Grant et al. (2008) completed a synthesis on the effects of forest management on peak flows and found no field studies that explicitly link peak flow changes to channel morphology. An unpublished study by MacDonald et al. (1995) found no correlation between channel dimensions and the degree of management (timber harvest and roads) on the Kootenai National Forest.

This cursory analysis of stream channel and aquatic habitat attributes certainly identifies some relationships and patterns that need to be explored in more detail. Advanced statistical techniques, such as multiple regression, may provide additional insight into the effects of management activities on channel morphology and aquatic habitat.

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